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Technical News BULLETIN

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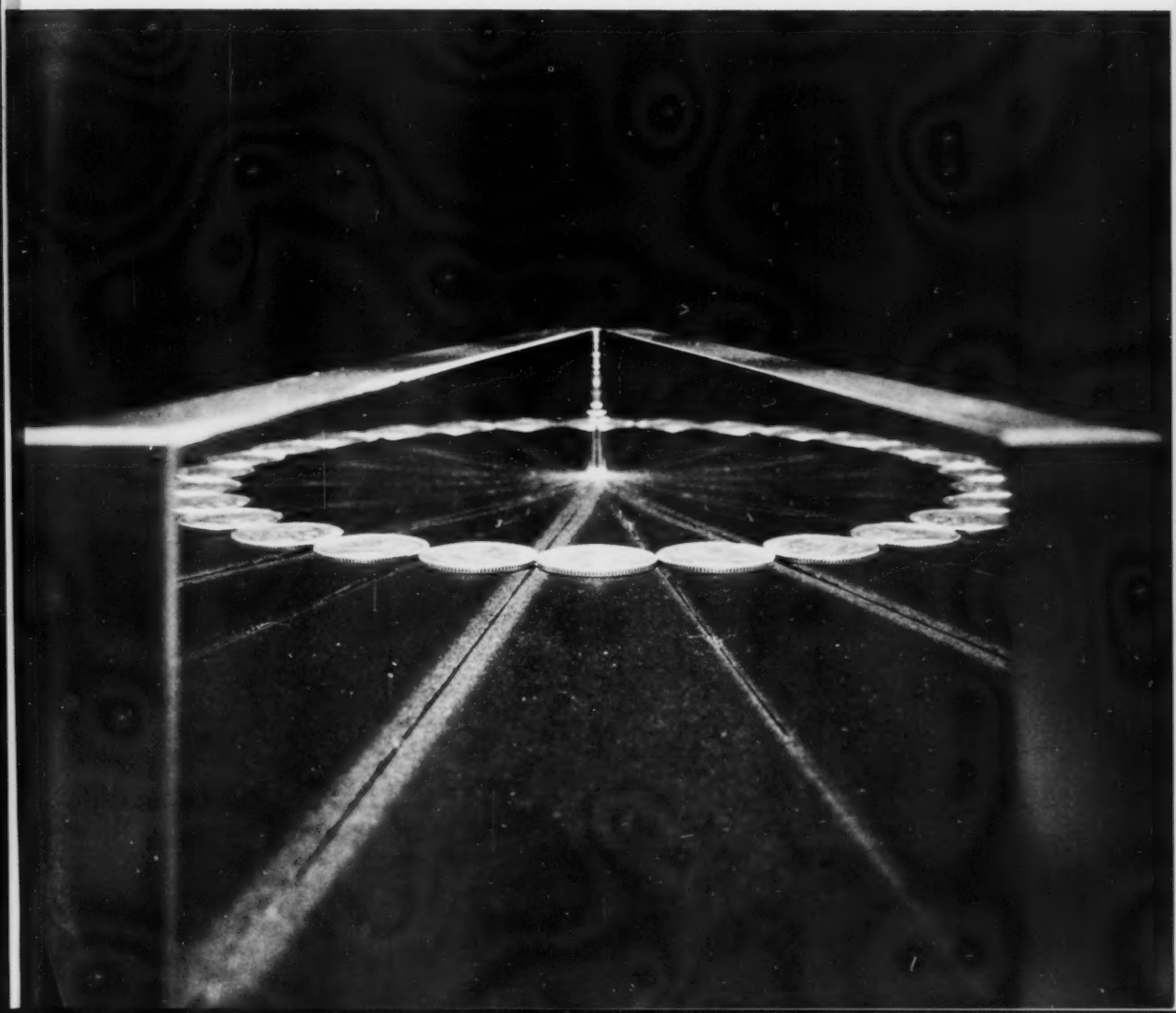

U.S. DEPARTMENT OF COMMERCE — LUTHER H. HODGES, *Secretary*

NATIONAL BUREAU OF STANDARDS — A. V. ASTIN, *Director*

NATIONAL BUREAU OF STANDARDS

Technical News

BULLETIN

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. Subscription price, domestic $1.50 a year; 75 cents additional for foreign mailings; single copy, 15 cents. Use of funds for printing this publication approved by the Director of the Bureau of the Budget (June 19, 1961).

March 1963 — Issued Monthly — Vol. 47, No. 3

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COVER: A convenient reference angle, accurate to 0.02 second of arc, has been developed at NBS. The reference consists of two plane mirrors facing each other to form a wedge. Exact multiples of the included angle appear by reflection in each mirror. After interferometric determination of the angle between the mirrors, the images can be used as references for duplication of the original angle, thus permitting the calibration of a circle with a minimum number of readjustments of the wedge (see p. 47).

Accurate Alinement Interferometer

A SIMPLE interferometer for the optical alinement of light sources along a path several miles long, or for determining the displacement of a light source from a known axis, has been developed by J. B. Saunders of the engineering metrology laboratory.[1] This device, which is compact, rugged, and highly sensitive, permits the positioning of a small light source to within 0.04 mm at a distance of 1600 m. Among the potential applications of the interferometer is the alinement of the tubes of long linear accelerators.

The interferometer consists of two Kösters prisms,[2] one in line with and the other at right angles to the incoming light. A beam divider (a semireflecting mirror) is positioned to direct the light into the two prisms (see diagram, below, right). A Kösters prism is made of two 30–60–90 degree prisms fastened together, and has a semireflecting interface. This prism exhibits a series of fringes at right angles to its edge when the source is alined with its dividing plane or interface. The use of two prisms, with the planes of their dividing surfaces at right angles to one another, permits the accurate location of a source on the intersection of the two planes. When the distance to the source is known, the displacement of the source from the axis of the prisms can be computed from the order of interference measured at a reference point. The theoretical formula for sensitivity was confirmed with experiments over a 75-m path.

When a Kösters prism having a convex front surface is used in conjunction with a sufficiently bright source, fringes can be observed without the inclusion of any other optics. However, as the precision and sensitivity of this interferometer depend on its aperture, and as Kösters prisms with large apertures are difficult to produce, the aperture of the system can be increased, when necessary, by the use of a telescope. If, for example, a Cassegrainian system is used, light from sources near the interferometer (i.e., light which needs no concentration) enters without reflection, whereas light from more distant sources is reflected before entering.

A small white-light source, such as a zirconium arc lamp, serves quite well for use with this interferometer. White light, however, must be passed through a mica ¼-wave plate to provide the proper polarization. One limitation of this interferometer, however, is the instabilities in the fringe pattern caused by atmospheric inhomogeneities. An extremely quiet atmosphere or, better still, an evacuated system is necessary for its most effective utilization.

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[1] An alinement interferometer, *by J. B. Saunders, submitted to J. Opt. Soc. Am.*

[2] Construction of a Kösters double-image prism, *by J. B. Saunders, J. Research NBS* **58**, *21 (Jan. 1957).*

Top: **Using the alinement interferometer, J. B. Saunders examines fringes (*not visible*) in the interference element—a Kösters prism. The orientation of the fringes depends upon the placement of the source with respect to the dividing plane of the prism. The lens at the right is used to increase the aperture of the system. The use of a beam divider and a second prism would permit alinement in two planes.** ***Below:*** **Interferometer for the accurate alinement of light sources at distances up to several miles. Incoming light from source (*S*) is sent by beam divider (*B*) to two Kösters prisms (*C* and *D*). When the source is in line with the dividing planes of these prisms, interference fringes will be formed at right angles to the prisms' edge. Prism *D* is rotated relative to *C* so that its dividing plane is parallel to the figure, thus permitting the positioning of the source in two planes. Lateral alinement to within 0.04 mm at 1600 m is possible.**

RADIO MEASUREMENTS of a Manmade Radiation Belt

THE BUREAU'S Jicamarca, Peru, Observatory, in cooperation with the Geophysical Institute of Peru, has made a series of measurements of the synchrotron* radiation emitted by the manmade belt of high-energy electrons formed by a high-altitude nuclear detonation.[1] From these measurements, made at 30 and 50 Mc/s, the number, energy spectrum, and decay rate of the electrons have been derived. This information contributes to an improved understanding of the physics of the upper atmosphere.

The test shot from which this radiation belt resulted was fired at a height of about 400 km above Johnston Island in the Pacific on July 9, 1962. The electrons formed by the explosion were trapped by the earth's magnetic field in a doughnut-shaped region extending approximately 20 deg north and south of the magnetic equator. Measurements of this belt have been made by the Bureau with ground-based equipment and by the National Aeronautics and Space Administration with satellite instruments.

Three receiving systems were used by NBS to measure the radiation from the artificial belt, the most important of which is an array of crossed dipoles at Jicamarca covering an area of 288 by 288 m (about 22 acres). Half of this antenna was used to make total radio-noise power measurements at 50 Mc/s, and the other half connected so that it could be rapidly switched from north-south to east-west polarization, the difference between these two polarizations being displayed. Two smaller radio antennas, both operating at 30 Mc/s, were also used, one at Jicamarca and the other at nearby Huancayo. The three antennas are situated close to the magnetic equator, where the lines of the earth's magnetic field are horizontal.

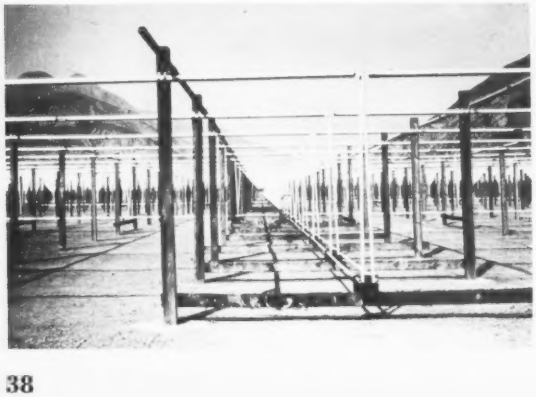
The record of the radio-noise power at the time of the detonation indicates a large increase some 6 min after the blast, corresponding to the first passage of the energetic electrons over the antennas. The magnitude of this peak is shown by the fact that the equivalent noise diode current of the 50 Mc/s antenna is 12 ma, and the peak current corresponding to the first passage of the electrons was about 105 ma. About 25 min after the first peak, a second, less well-defined peak occurred, denoting the second passage of the electrons. Thereafter, due to the spreading in longitude of the electrons resulting from their different speeds, a general level of radiation well above that of the usual noise background prevailed. The synchrotron radiation, as shown by the difference in the polarization measurements, is almost linear.

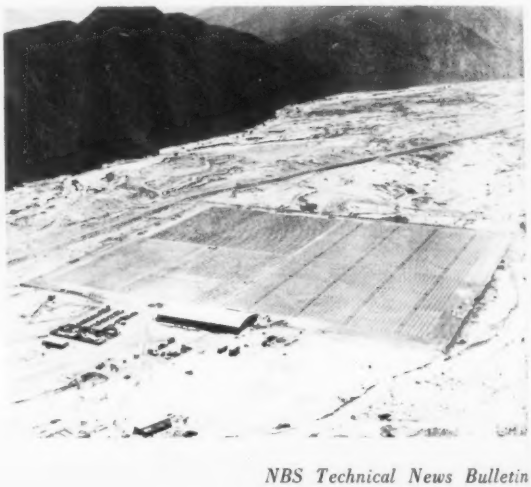
The slow decay of this radiation is seen from a day-by-day plot of measurements made at 30 Mc/s (see illustration). Most of the measurements were made at (and the others normalized to) 0600 hr local time, a time when ionospheric absorption is quite low. Two months after the test firing about one half of the radiation had decayed, and the rate of decay is thought to be decreasing. Therefore, at least 15 percent of the original synchrotron radiation may be present after one year.

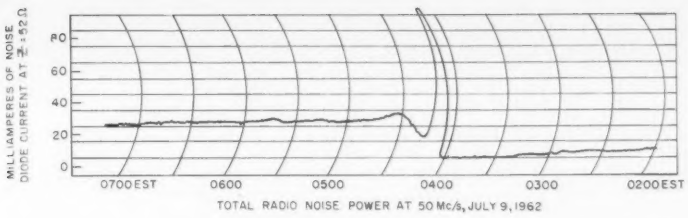
The energy spectrum of the electrons has been calculated from the time-intensity plot of their first passage, as the time of arrival of an electron is a function

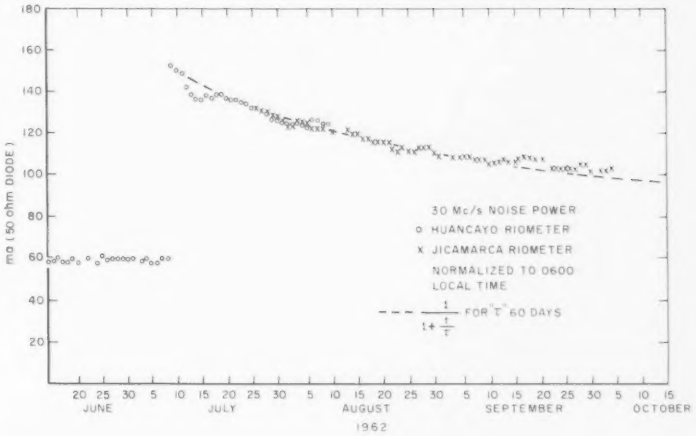
**The electromagnetic radiation emitted by energetic electrons moving in a magnetic field is called synchrotron radiation because it was first discovered in studies involving the particle accelerator called a synchrotron.*

Left: **A portion of the dipole antenna, located at Jicamarca, Peru, used in the measurement of the artificial radiation belt.** ***Right:*** **Air view of the 22-acre antenna during construction.**









Above: **Record of part of a series of measurements of the radio noise emitted by the electrons resulting from high-altitude atomic test. The large peak in the radio-noise record corresponds to the first passage of the electrons over the antenna some 6 min after the explosion.** ***Right:*** **Measurements at 30 Mc/s of the radio noise emitted by the manmade radiation belt show a slow decline in intensity. At the current rate of decrease, at least 15 percent of the original power will remain one year from inception.**

of its energy or speed. On the assumption that the mean altitude of the electrons is about 1500 km (a figure substantiated by satellite measurements), a plot of the observed spectrum was obtained which agrees closely with the expected spectrum resulting from the explosion. The highest energy recorded was somewhat over 6 Mev, although errors in measurement could have masked electrons of higher energy.

Calculations based upon the experimental results were also made of the number of electrons in the radiation belt. When the efficiency of the antenna for the detection of polarized radiation is taken into account, a rough total of somewhat over 10^{24} electrons is obtained. This figure agrees with estimates made from satellite measurements.

[1] *See* Observations of synchrotron radio noise at the magnetic equator following the high altitude nuclear explosion of July 9, 1962, *by G. R. Ochs, D. T. Farley, K. L. Bowles, and P. Bandyopadhay, to appear in J. Geophys. Res. See also* Artificial radiation belt discussed in symposium at Goddard Space Center, *Science* **138,** *53 (Oct. 5, 1962).*

SMALL CALORIMETERS FOR ABSORBED DOSE MEASUREMENTS

ABSORBED DOSE calorimeters in which the mass of the absorbing material is less than 1.5 g have been developed by Ben Petree and George Ward of the radiation physics laboratory. Two such devices have been constructed under Atomic Energy Commission sponsorship—one of graphite and another of aluminum. These calorimeters, which are of simple design, can be used with X- or gamma-ray dose rates in excess of 1 rad (100 ergs/gram) per second, and are accurate to within 1 percent or better.[1]

The effect of radiation on any material results from the absorption of energy. One way to determine the absorbed dose in a material is to make measurements of the ionization resulting from the radiation in a gas within a cavity of the material and then, with suitable conversion factors,* calculate the absorbed dose. This method is widely used, but is limited by the accuracy with which the conversion factors are known, and by the maximum dose rate that can be measured by the ionization technique. A more direct method for determining the absorbed dose is used in these Bureau-developed devices—the measurement of the temperature rise associated with the absorption of radiation.

**The factors which must be known are* W, *the average energy required to produce an ion pair in the gas used in the ionization chamber; and* s_m, *the ratio of the stopping powers of the material in which the absorbed dose is being determined to that of the gas in the cavity.*

Small absorbed-dose calorimeter developed by the Bureau. The radiation is absorbed in the aluminum cylinder at the right, and the temperature rise due to this absorption is recorded. In use, the cylinder fits within the shield to the left. Heater wires (wound externally on the shield to keep it at the same temperature as the core), and the shield and core thermocouple wires are not shown.

Dimensional data on small absorbed-dose calorimeters

	Graphite	*Aluminum*
Mass of absorbing core	0.9 g	1.4 g
Shield wall thickness	0.4 cm	0.102 cm
Shield diameter, outside	2.2 cm	1.32 cm
Shield height	spherical	0.880 cm
Core-to-shield spacing, radial	0.2 cm	0.051 cm
Core-to-shield spacing, top and bottom	---	0.020 cm

The two Bureau chambers differ somewhat in geometry (see table) due to the applications for which they are intended. The first, made of carbon, is spherical, as it is used to measure the gamma-ray dose coming from all directions within a circular "picket fence" cobalt 60 source. The other, made of aluminum, is cylindrical, as it is irradiated axially with X-rays.

The calorimeters consist essentially of a small inner core, in which the temperature rise (about 3 °C with the doses measured) resulting from the absorption of radiation is measured, and a surrounding shield of the same material that is kept as close as possible to the temperature of the core to reduce heat transfer. The carbon calorimeter is mounted in Styrofoam and, during measurements, is contained within a metal can that is evacuated to reduce heat transfer further. The aluminum calorimeter is mounted in an evacuated aluminum block during use.

The cores are made of halves cemented together with a film of epoxy resin containing carbon black. This binder not only holds the core together but, since it is electrically conducting, serves as a core heating element as well. Known amounts of electrical energy are passed into the cores to establish their thermal response to energy. Two thermocouples are held in small holes in the core with epoxy resin—one to indicate the core temperature and the other to help determine the core-shield temperature difference.

The shields are made in two pieces which fit tightly together around the core, the separation between core and shield being quite small. Polystyrene spacers between the core and shield keep these pieces in the proper relative position. The shields are wound with closely and evenly spaced heater wires which permit the adjustment of their temperature to coincide with that of the core.

A single thermocouple is fastened to the inner surface of the shield. This thermocouple, in a circuit with one of those attached to the core, is used to determine the core-shield temperature difference. In the carbon calorimeter the current supplied to the shield heater is adjusted by an operator in response to an indication of this temperature difference; provisions were made in the aluminum calorimeter to regulate the heating automatically.

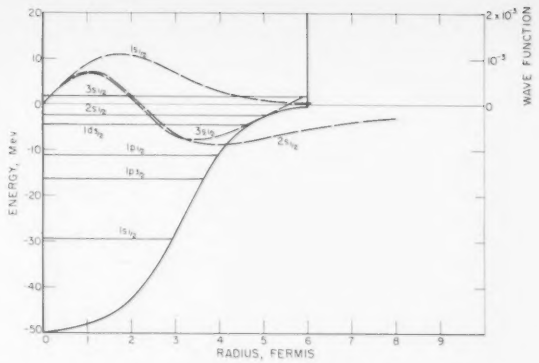
The precision of these calorimeters is indicated by the results of a number of electrical calibrations, which give a standard deviation of mean sensitivity of the graphite chamber of 0.14 percent and of the aluminum, 0.5 percent. A comparison was made between the dose rate calculated from an ionization measurement and that actually measured with the carbon calorimeter. Here, the difference between the two results was 0.7 percent.

[1] The construction of calorimeters for the measurement of absorbed dose, *by Ben Petree and George Ward, NBS Tech. Note 163, available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. Price 25 cents.*

AUTOMATIC COMPUTATION OF EIGENVALUES IN REAL POTENTIAL WELLS

A COMPUTER program for the computation of eigenvalues and eigenfunctions for neutrons in real potential wells has been developed at the Bureau. The real (i.e., no complex numbers involved in theoretical description) potential well under consideration represents the average force of all the other particles in the nucleus upon the one neutron under consideration. The computations are useful in providing input information for calculations of the structure of nuclei by means of a nuclear shell model.

Nuclear shell model calculations have until now employed harmonic oscillator wave functions almost exclusively in evaluating the energies of both the bound states and those states which actually belong to the con-



Eigenvalues and the first three eigenfunctions for orbital angular momentum equal to zero in a Woods-Saxon potential well. The parameters of the well are well depth =−50 Mev; radius =3.15 fermis; diffuseness parameter =0.650 fermis; spin-orbit term is 35 times the Thomas term. The shape of the well shown is for orbital angular momentum equal to zero. During the survey procedure, the maximum radius is given by the heavy black line, the edge of the well for bound states, and 6.0 fermis for continuum states.

tinuum. However, the character of the wave functions for the bound states is quite different from that of the true wave functions for the continuum or scattering states, so that errors are introduced. A treatment of the continuum states therefore requires more accurate functions than those of the harmonic oscillator representation.

The computer program,[1] originated by R. S. Caswell of the neuton physics laboratory, uses a systematic search procedure to find approximate eigenvalue locations and an automatic search procedure to determine exact locations. The calculations are made for a particular potential well (Woods-Saxon) with established boundary conditions, but the code may be easily modified for use with other well shapes.

In the systematic search procedure, the energy range of interest is scanned for the case of a simplified well to find approximate eigenvalue locations. An approximate eigenvalue is then assumed and the automatic search procedure is started. Wave functions are integrated out in radius and matched to asymptotic solutions outside the nuclear surface. Successive improved values for the energy level locations are tested and evaluated by the difference between the inside and outside wave functions.

When the correct eigenvalue is determined, the wave function versus radius is printed. Eigenvalue accuracy obtained by this method is much better than is required by present knowledge of potential well shapes and depths.

[1] A Fortran code for calculation of eigenvalues and eigenfunctions in real potential wells, *by Randall S. Caswell, NBS Tech. Note 159 (1962). For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. Price 25 cents.*

Course in Electromagnetic Measurements and Standards

AN INTENSIVE, 3-week, graduate-level course in Electromagnetic Measurements and Standards will be offered July 22 to August 9, 1963, by the Graduate School of the Bureau in association with the University of Colorado.

Highest level performance and exacting operation of complex systems in aerospace, military defense, atomic energy, and communications cannot be achieved without the establishment of precise, accurate, and uniform measurements. This course will assist technical supervisors of standards and measurements laboratories, practicing engineers, and university faculty and graduate students who are concerned with the field of radio science to meet responsibilities for such measurement.

Major areas of study will be: (1) A brief review of basic electromagnetic and circuit theory; (2) principles of the measurement system of science including its basis, structure, terminology, and uncertainties; (3) measurement of essential quantities in the special areas of low, high, and microwave frequencies; (4) topics important at all frequencies such as frequency standards (e.g., atomic beams), power, noise, attenuation, electromagnetic properties of materials, and foreseeable needs in frontier areas such as millimeter waves, plasmas, and quantum electronics. There will be more than 50 lectures in all and these will be supplemented by regularly scheduled informal discussions conducted by all lecturers within a particular topic group.

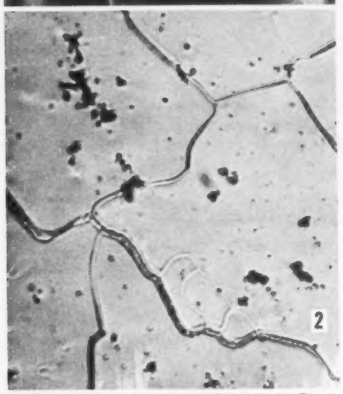
These presentations will be at the frontiers of development and will be given by specialists who, in most cases, are authorities in their fields. Emphasis will be upon the present state of the art with some consideration of future needs.

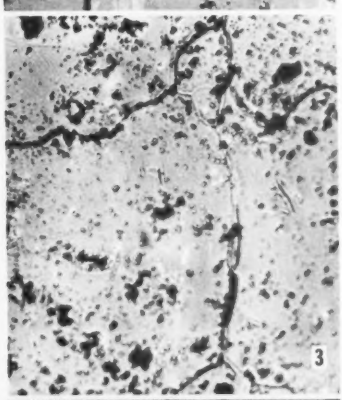
Prerequisites: a bachelor's degree in electrical engineering, physics, or other suitable academic or practical experience which is judged equivalent by the Registrar.

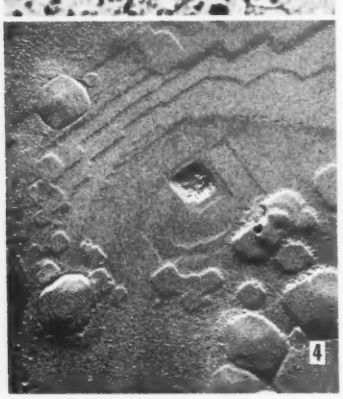
Tuition: approximately $350 (with a slight additional charge for those desiring graduate credit).

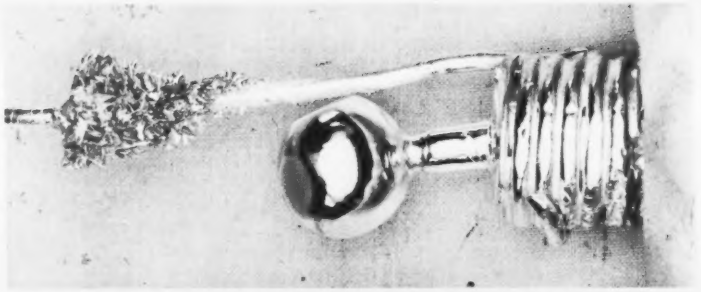
Graduate credit: Upon satisfactory completion of the course, three semester-hours' credit may be earned through the Department of Electrical Engineering at the University of Colorado. Students registering for credit must submit solutions to the problems assigned throughout the course and must plan to remain an additional half day to write a final examination. In addition to the tuition charge, these students will be required to pay a $15 registration fee to cover expenses at the University of Colorado.

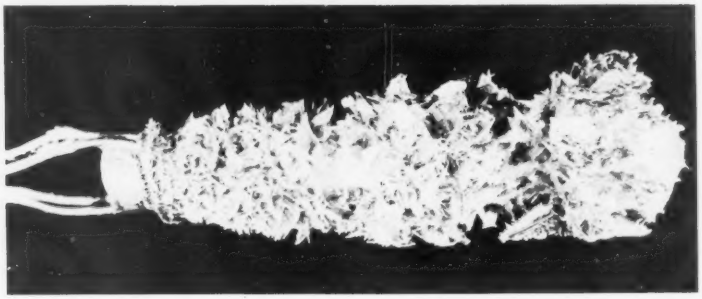
Registration: Will be limited and early application should be made to insure consideration. Registration will be closed July 1, 1963. Further details and registration forms are available from: Edmund H. Brown, Education Director, Boulder Laboratories, National Bureau of Standards, Boulder, Colo.







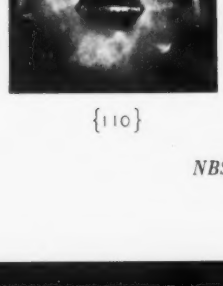




Left: **Photomicrographs of crystal surfaces after exposure to molten sodium chloride. (1) Electron micrograph of a negative Parlodion replica shows a portion of a cell-like network that developed as ridges on a silver single crystal. The width of ridge is 2 to 3 μ. (2 & 3) Two views of a {111} crystal surface that had been exposed to the melt at 900 °C for 4 days: (2) exposed to the hot end of the gradient, and (3) to the cold end. (4) Electron micrograph of pit and hillock formations observed on the {100} crystal surface exposed for 24 hr at 900 °C.**

Thermal gradient produces the most pronounced effect on the corrosion of silver single crystals in sodium chloride. *Top:* crystal and wire holder exposed in an alumina crucible at 900 °C for 4 days. Dendritic crystals grew on the wire at the cold end of the thermal gradient. *Above:* crystal and holder exposed at 900 °C in a silver crucible for 15 hr. Crystals formed over the entire assembly. Gradient existed between the assembly and the crucible wall. *Below:* Faceted crystals deposited on three different crystallographic planes of a silver single crystal exposed for 15 hr. The orientation of the crystals shows an epitaxial relationship to the various planes on which they grew.

{100}



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{111}

Corrosion of Silver Single Crystals in Molten Salts

TO OBTAIN basic data on metal corrosion by molten salts, Jerome Kruger and Kurt H. Stern of the metal reactions laboratory recently exposed silver single crystals to fused sodium chloride under a variety of experimental conditions. The most pronounced effect observed was the influence of a thermal gradient on etching and deposition processes occurring on the crystal surface.[1]

Molten salts, which are inexpensive and generally have high heat capacity, high thermal conductance, and low vapor pressure, are potentially useful in nuclear reactor applications, especially as a fuel or coolant, or as media for nuclear fuel processing. However, salts are highly corrosive to metallic container materials and corroded parts in molten salt systems are not easily repaired. The present research was therefore undertaken to gain a better understanding of the reactions involved in such corrosion, particularly to determine whether the rate of reaction varied on different crystallographic planes.

Several single crystals of silver in the form of ¾-in.-diam spheres were grown in graphite molds for the experiments. Flat surfaces parallel to the {100}, {110}, and {111} crystallographic planes were ground at appropriate sites on each sphere and, in addition, a surface parallel to the {211} plane was ground on one of the spheres. Each crystal was mounted in a silver holder and immersed in a crucible containing sodium chloride. The crucible was then heated in a furnace to 900 °C and held at that temperature for the duration of the exposure period. Most of the exposures were carried out in the presence of air, in either alumina or silver crucibles.

In the experimental arrangement in which an alumina crucible was used, a silver wire, which was part of the crystal holder, extended up out of the molten salt into the air. Thus a thermal gradient existed between the crystal at the bottom of the crucible and the top of the wire at the air-salt interface. When the crystal assembly was removed from the melt after 4 days of exposure, profuse dendritic deposits were found on the wire near the interface (the coolest part of the system), while the crystal itself and its various plane surfaces appeared quite smooth.

In the experimental arrangement in which a silver crucible was used, the thermal gradient existed between the crystal with its holder and the heated wall of the crucible. When this assembly was removed from the melt after 15 hr of exposure, it was covered with dendrites and small faceted crystals had deposited on the crystal itself. The orientation of the faceted crystals varied according to the crystallographic planes on which they grew. Silver dissolved at the higher temperature end of the gradient and deposited at the lower temperature end. This result is attributed to shifts in equilibria with increasing temperature, as proposed earlier by Stern.[2] Such shifts apparently produce silver ions which form the corrosion product.

Microscopic examination showed subgrain boundaries delineated in a cell-like network on the various plane surfaces of crystals exposed under both experimental arrangements; so negative Parlodion replicas were made of these surfaces for more detailed study with an electron microscope. Photomicrographs thus obtained showed that the boundaries were ridges projecting from the specimen surfaces. Studies with an electron probe microanalyzer disclosed that the boundaries contained iron impurities, and that little, if any, detectable iron was present in the cell interiors. Since the experiments were carried out in the presence of air, impurities in the silver apparently oxidized to the oxides stable at 900 °C, and ferric oxide—which is nearly insoluble in molten salt—remained in the crystal as the silver dissolved.

Besides the subgrain boundaries on the crystal surface, small hillocks were also observed with the electron microscope. The number of these hillocks occurring per unit area was affected by the position of the crystal in the thermal gradient, with more hillocks forming at the cooler than at the hotter end.

Other investigators have reported[3] that mass transfer of silver in fused chloride melts occurs only when there is a metallic connection between the hot and cold ends of a thermal gradient. They suggest that a thermocell mechanism is involved in such transfer. However, in the present experiments, when the gradient existed between the crucible and specimen, the two were not connected, yet mass transfer occurred. Thus it appears that shifts in equilibria rather than a thermocell mechanism may cause silver to dissolve at higher and deposit at lower temperatures.

In another experimental arrangement, the thermal gradient was eliminated by the use of a muffle furnace as the heating unit. In this environment, no mass transfer of silver occurred for 24-hr exposure periods. When the surface of the exposed silver crystal was studied with the electron microscope, square pits and spirals were observed on some of the planes studied. The pits formed at imperfect sites, for example, at dislocations in the crystal lattice. Pits were found on the {100} surfaces; some pits and steps appeared on the {111}, but none on the {110} and {211} surfaces. Such findings indicate that, in the absence of a thermal gradient, dislocations and the crystallographic orientations may affect the corrosion behavior.

[1] *For further technical details, see* Surface behavior of silver single crystals in fused sodium chloride, *by Jerome Kruger and Kurt H. Stern, J. Electrochem. Soc.* **109,** *889–894 (1962).*

[2] Oxidation of metals in molten salts. Silver in sodium chloride, *by Kurt H. Stern, J. Phys. Chem.* **66,** *1311–1317 (1962); also,* Oxidation of metals in molten salts, *NBS Tech. News Bull.* **47,** *No. 2 (1963).*

[3] Mass transfer of metals in fused-chloride melts, *by C. Edeleanu and J. G. Gibson, J. Inst. Metals* **88,** *321 (1960).*

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PERIODIC ARRANGEMENT OF THE MBLL

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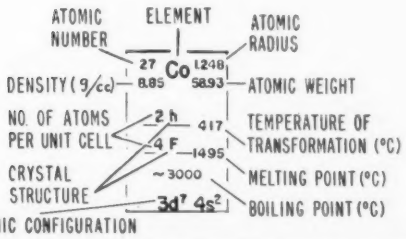
2	3 Li 1.52 0.534 6.939 2 h -196 2 B 180.54 1330 1s² 2s	4 Be 1.11 1.848 9.012 2 h 1250 2 B 1284 2507 1s² 2s²	5 B 0.97 2.34 10.811 R 1200 T 1500 R 2030 2550 2s² 2p	6 C 0.71 2.27 12.011 Graphite H Diamond D 3727 4830 2s² 2p²	7 N 0.71 .0125 14.006 H -209.97 -195.8 2s² 2p³	8 O 0.60 .001429 15.999 C -218.83 -183.0 2s² 2p⁴	CRYSTAL STRUCTURE C CUBIC B B.C.CUBIC F F.C.CUBIC H HEXAGONAL h C.P.HEXAGONAL D DIAMOND CUBIC R RHOMBOHEDRAL O ORTHORHOMBIC T TETRAGONAL t F.C.TETRAGONAL U B.C.TETRAGONAL M MONOCLINIC				
3	11 Na 1.857 0.9712 22.98 2 B 97.81 883 2p⁶ 3s	12 Mg 1.598 1.74 24.31 2 h 650 1107 2p⁶ 3s²	13 Al 1.431 2.699 26.98 4 F 660 2450 3s²3p	14 Si 1.175 2.328 28.08 8 D 1410 2480 3s²3p²	15 P 1.823 30.97 Black 80 Red 66 C White C 44.25 280 3s²3p³	16 S 1.06 2.07 32.06 128 O 95 48 M 119.0 444.6 3s²3p⁴					
4	19 K 2.312 0.86 39.10 2 B 63.7 760 3s² 3p⁶ 4s	20 Ca 1.97 1.55 40.08 4 F 464 2 B 851 1482 3s² 3p⁶ 4s²	21 Sc 1.602 2.99 44.95 2 h 1335 1539 2730 3d 4s²	22 Ti 1.444 4.54 47.90 2 h 882 2 B 1668 3260 3d² 4s²	23 V 1.316 6.11 50.94 2 B 1900 ~3400 3d³ 4s²	24 Cr 1.249 7.19 51.99 2 B 1875 2665 3d⁵ 4s	25 Mn 1.12 7.43 54.93 58 C 742 20 C 1095 4 F 1134 2 B 1245 2097 3d⁵ 4s²	26 Fe 1.241 7.874 55.84 2 B 910 4 F 1390 2 B 1536.5 ~3000 3d⁶ 4s²	27 Co 1.248 8.85 58.93 2 h 417 4 F 1495 ~3000 3d⁷ 4s²	28 Ni 1.245 8.902 58.71 4 F 1453 2730 3d⁸ 4s²	29 Cu 8.96 4 F 259 3d¹⁰
5	37 Rb 2.44 1.53 85.47 2 B 39 688 4s² 4p⁶ 5s	38 Sr 2.155 2.60 87.62 4 F 215 2 h 605 2 B 768 1380 4s² 4p⁶ 5s²	39 Y 1.78 4.472 88.90 2 h 1460 2 B 1509 2930 4p⁶ 4d 5s²	40 Zr 1.585 6.489 91.22 2 h 862 2 B 1852 3580 4p⁶ 4d² 5s²	41 Nb 1.426 8.57 92.90 2 B ~2468 3300 4p⁶ 4d⁴ 5s	42 Mo 1.36 10.22 95.94 2 B 2610 5560 4p⁶ 4d⁵ 5s	43 Tc 1.358 11.5 98.98 2 h ~2150 4p⁶ 4d⁵ 5s²	44 Ru 1.32 12.4 101.07 2 h ~2250 4900 4p⁶ 4d⁷ 5s	45 Rh 1.345 12.44 102.90 4 F 1960 4500 4p⁶ 4d⁸ 5s	46 Pd 1.378 12.02 106.4 4 F 1552 3900 4p⁶ 4d¹⁰	47 Ag 10.49 4 F 221 4d¹⁰5
6	55 Cs 2.62 1.873 132.90 2 B 28.7 705 5p⁶ 6s	56 Ba 2.174 3.5 137.34 2 B 710 1500 5p⁶ 6s²	La—Lu	72 Hf 1.56 13.09 178.49 2 h 1760 2 B 2150 5400 5d² 6s²	73 Ta 1.430 16.6 180.94 2 B 3000 ~6100 5d³ 6s²	74 W 1.367 19.3 183.85 2 B 3410 5930 5d⁴ 6s²	75 Re 1.37 21.04 186.2 2 h 3180 5900 5d⁵ 6s²	76 Os 1.34 22.58 190.2 2 h 3010 5500 5d⁶ 6s²	77 Ir 1.357 22.42 192.2 4 F 2410 ~5300 5d⁷ 6s²	78 Pt 1.387 21.4 195.09 4 F 1769 4530 5d⁹6s	79 Au 19.32 4 F 297 5d¹⁰6
6	57 La 1.87 6.19 138.91 2 h 310 4 F 868 2 B 920 3470 5d 6s²	58 Ce 1.82 6.66 140.12 4 F -150 H -10 4 F 730 2 B 795 3470 4f² 6s²	59 Pr 1.82 6.782 140.90 4 H 790 2 B 935 3130 4f³ 6s²	60 Nd 1.81 7.00 144.24 4 H 862 2 B 1024 3030 4f⁴ 6s²	61 Pm ~145 H >425 4 F 1035 2730 4f⁵ 6s²	62 Sm 1.80 7.536 150.35 3 R 917 1072 1900 4f⁶ 6s²	63 Eu 2.04 5.25 151.96 2 B 826 1440 4f⁷ 6s²	64 Gd 1.79 7.895 157.25 2 h 1264 2 B 1312 3000 4f⁷5d6s²	65 Tb 1.76 8.272 158.92 2 h 1317 1356 2800 4f⁹ 6s²	66 Dy 1.77 8.536 162.5 2 h 140 2600 4f¹⁰6s²	67 Ho 8803 2 h 2 4f¹¹ 6
7	87 Fr 223 ~27 6s²6p⁶7s	88 Ra 5.0 226.05 ~700 6p⁶ 7s²	89 Ac 10.07 227.05 F 1050 6p⁶ 6d 7s²	90 Th 1.704 11.66 232.03 4 F ~1400 2 B 1750 ~4200 6d² 7s²	91 Pa 1.63 15.4 231.1 2 U ~1230 5f¹6d² 7s²	92 U 1.38 19.07 238.03 4 O 667.7 30 T 774.8 2 B 1132.3 3815 5f³6d 7s²	93 Np 1.3 20.45 237 8 O 280 4 T 577 2 B 637 5f⁵ 7s²	94 Pu 239.11 19.84 16 M 122 8 O 206 4 F 319 U 451 2 B 639.5 3235 5f⁶ 7s²	95 Am 243 11.7 2 h 600 4 F 995 5f⁷ 7s²	96 Cm 24 5f⁷6d 7s²	97 Bk 5f⁹ 7

R.C. – Body-centered F.C. – Face-centered C.P. – Close-packed

METALLURGICAL ELEMENTS

VIII I II III IV V VI

READING KEY



28 Ni 1.246 8.90 58.71 4 F 1453 2730 3d⁸ 4s²	29 Cu 1.278 8.96 63.54 4 F 1083.0 2595 3d¹⁰ 4s	30 Zn 1.3324 7.133 65.37 2 h 419.505 906 3d¹⁰ 4s²	31 Ga 1.2185 5.907 69.72 8 O 29.78 2237 4s² 4p	32 Ge 1.2245 5.323 72.59 8 D 937.4 2830 4s² 4p²	33 As 1.25 5.727 74.92 2 R 817 613 SUBLIMES 4s² 4p³	34 Se 1.16 4.79 78.96 M 40-50 3 H 217 685 4s² 4p⁴
46 Pd 1.378 10.64 106.4 4 F 1552 3980 4d¹⁰	47 Ag 1.444 10.49 107.87 4 F 960.80 2210 4d¹⁰ 5s	48 Cd 1.48 8.65 112.40 2 h 320.9 765 4d¹⁰ 5s²	49 In 1.625 7.31 114.82 4 U 156.17 2075 5s² 5p	50 Sn 1.51 7.29 118.69 8 D 13.2 4 U 231.91 2270 5s² 5p²	51 Sb 1.452 6.68 121.75 2 R 630.5 1440 5s² 5p³	52 Te 1.285 6.25 127.60 3 H 449.5 990 5s² 5p⁴
78 Pt 1.387 21.45 195.09 4 F 1769 4530 5d⁹ 6s	79 Au 1.441 19.32 196.96 4 F 1063.0 2970 5d¹⁰ 6s	80 Hg 1.50 13.546 200.59 1 R -38.36 357 5d¹⁰ 6s²	81 Tl 1.704 11.85 204.37 2 h 230 2 B 303 1457 5d¹⁰ 6s² 6p	82 Pb 1.75 11.36 207.19 4 F 327.42 1725 5d¹⁰ 6s² 6p²	83 Bi 1.555 9.80 208.98 2 R 271.3 ~1600 6s² 6p³	84 Po 1.7 9.4 ~210 C ~ 50 R 254 6s² 6p⁴
66 Dy 1.77 8.803 162.51 2 h 1407 2600 4f¹⁰ 6s²	67 Ho 1.74 8.803 164.93 2 h 1461 2600 4f¹¹ 6s²	68 Er 1.73 9.15 167.26 2 h 1497 2900 4f¹² 6s²	69 Tm 1.72 9.332 168.93 2 h 1545 1730 4f¹³ 6s²	70 Yb 1.93 6.977 173.04 4 F 798 2 B 824 1430 4f¹⁴ 6s²	71 Lu 1.74 9.842 174.97 2 h 1652 3330 4f¹⁴ 5d 6s²	
98 Cm 247 5f⁷ 6d 7s²	97 Bk 249 5f⁹ 7s²	98 Cf 251 5f¹⁰ 7s²	99 Es 254 5f¹¹ 7s²	100 Fm 253 5f¹² 7s²	101 Md 256 5f¹³ 7s²	102 No ~247 5f¹⁴ 7s²

Compiled by L. L. Wyman & J. J. Park NBS 1961

This National Bureau of Standards chart is a compilation of elementary data in the form of a periodic table. The chart gives the different crystal lattice structures and the applicable transformation temperatures of the metallurgical elements up to their melting points. Such data, of particular interest to metallurgists, are not included in the more conventional type of periodic table of the elements.

The transformation temperatures shown are for solid-to-solid transitions. It is known that extensive solid solubility of two or more metals is most likely if the metals have matching or related crystal structures, together with similar atomic radii and comparable electronic configurations. Thus, with this chart, certain alloying characteristics of the metallurgical elements may be postulated, and experimental alloying to develop improved materials may be facilitated.

The data used in the chart have been selected from authoritative sources and are the most recent available at the time of compilation. The atomic weights, for example, are those adopted by the International Union of Pure and Applied Chemistry in 1961. These weights are based on the assigned atomic mass (12) of the principal carbon isotope which was chosen to supersede the oxygen isotope (mass 16) previously used.

The upper and lower case designations that are employed to specify crystal lattice structures follow a 1961 proposal of the Committee on Metallography of the American Society for Testing and Materials (ASTM), now published as ASTM Recommendation E157–61T. A numerical prefix is also used to show the number of atoms per unit cell of a particular crystal lattice structure. With this system, arbitrary Greek symbols previously employed to identify various alloying phases are eliminated and rapid comparison of relevant crystal structures may be made.

Hydrogen, nitrogen, and oxygen are shown in the chart because of the known effects of these elements upon certain metals, particularly iron and titanium. The halogens and inert gases have been excluded since they are not usually significant in metallurgical reactions. A logical arrangement is provided with the A-group elements listed on the left and the B-group elements on the right of the central VIII group.

Hafnium and Zirconium Quantitatively Analyzed

A METHOD for quantitatively analyzing hafnium and zirconium [1]—two chemically similar elements—has been developed at the Bureau. The method was designed by L. A. Machlan and J. L. Hague of the standard reference materials laboratory to facilitate the use of these two elements in nuclear reactor construction. For many purposes hafnium and zirconium can be considered as one constituent, but differences in their nuclear properties require knowledge of the relative amounts present for reactor applications.

L. A. Machlan introduces a solution containing hafnium and zirconium into an anion-exchange resin column. Compounds of each element are held by resin particles with varying affinity, thus allowing an otherwise difficult separation of hafnium from zirconium. The overhead bottles, connected to the columns with polyethylene tubes, contain eluting solutions.

Hafnium is found only in the presence of zirconium, usually in zircon ore, and the two elements react with other materials to form compounds that are difficult to separate by usual chemical means. In previous Bureau work,[2] a separation was accomplished by dissolving hafnium-zirconium metal or oxide specimens in hydrofluoric and sulfuric acids, then fuming off the hydrofluoric acid. After dilution with water, the solution was introduced into an anion-exchange resin column. As the solution flowed through the column, hafnium was separated from zirconium. The present work was undertaken to apply this separation technique to metal and oxide samples of various hafnium-zirconium ratios.

Solutions of hafnium and zirconium were collected separately from the column, and hydrochloric acid was added to each. The solutions were cooled, cupferron reagent was added to the specimens, and the precipitates thus formed were allowed to settle. The precipitates were subsequently filtered, washed, and

Anion-exchange resin columns set up as semi-permanent system. Approximately 12 hr are required for separating half-gram mixtures of hafnium and zirconium in this apparatus.

quantitatively transferred to platinum crucibles. The residues were dried at a low temperature, then ignited to constant weight at a high temperature to form hafnium or zirconium dioxides. Stoichiometric calculations were employed to determine the percent hafnium or zirconium present in the original specimens.

To determine the accuracy of this procedure, specimens of hafnium dioxide and zirconium dioxide were checked for purity by spectrographic means, then mixed to provide samples of known composition. Accuracy of between 2 and 5 parts per thousand was obtained on these samples.

With this method, separation and quantitative analysis of half-gram samples of material containing up to 20 percent zirconium could be made in approximately three days. Additional time was required for analyzing a sample containing between 20 and 80 percent zirconium. In concentrations higher than 80 percent zirconium, the metals tended to form chemical complexes which prevented quantitative analysis. Work is now under way to solve this problem, as part of a Bureau program to separate and analyze elements of the refractory metals group.

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[1] Separation of hafnium from zirconium and their determination: separation by anion-exchange, *by L. A. Machlan and J. L. Hague, J. Research NBS* **66A** *(Phys. & Chem.) No. 6 (Nov.–Dec. 1962).*

[2] Separation of hafnium from zirconium by anion exchange, *J. L. Hague and L. A. Machlan, J. Research NBS* **65A** *(Phys. & Chem.) No. 1, 75 (Jan.–Feb. 1961); and* Separation of hafnium from zirconium, *NBS Tech. News Bull.* **45,** *137 (Aug. 1961).*

Accurate Reference Angle Developed

A REFERENCE ANGLE accurate to 0.02 sec of arc, and reproducible in exact duplicates as a mirror image, has been developed by J. B. Saunders of the engineering metrology laboratory. This multiple reference,[1] formed by placing two plane mirrors to face one another and form a wedge, represents a considerable improvement over conventional interferometric angular references in both accuracy and convenience of use.

The usual interferometric reference angle [2] is formed by placing one rectangular mirror on top of another, crossed so as to form an X with the long arms horizontal. This reference is attached to the surface to be calibrated, and positioned so that light reflected from one of the mirrors forms a fringe pattern in an interferometer. The surface is then rotated until a similar pattern results from light reflected by the second mirror, the rotation being equal to the known angle between the mirrors. After each increment of rotation, however, the reference mirrors must be reset to permit a new measurement, and thus a relatively large cumulative error could occur.

In the arrangement used by the Bureau—two plane mirrors facing each other and forming a wedge—exact duplicates of the included angle appear as images in both mirrors. As each image serves as a reference for the calibration of a circle, the number of times the wedge must be repositioned is considerably reduced, and the cumulative error is correspondingly smaller.

To determine the angle between the two mirrors, an interferometer may be used in which light enters the wedge parallel to a bisector of the angle, and is reflected back and forth between the mirrors. At each reflection the angle of incidence is reduced by the angle between the mirrors, until the light is normal to one of the surfaces. It then retraces the same path back through the optics, recombining with light from a second arm of the interferometer. If the two sets of fringes (formed by light incident on each mirror of the wedge) are parallel, the angle is a precise subdivision of 180°. The approximate value of the angle can be determined by conventional means. If the fringes are not parallel, calculations based on the length of the mirrors, deviation of the fringes, and wavelength of the light will give the value.

Once the angle between the mirrors is accurately known, the wedge can be used to calibrate a circle. For example, the wedge could be mounted on the surface to be calibrated and positioned to receive light from a Kösters prism.[3] After an original condition of interference is established, interference will result, within the limits of the aperture of the wedge, at each angle of incidence that is a multiple of the included angle. This process can be repeated in either direction permitting, with, say, a 20-deg angle between the mirrors, calibration of a complete circle with but two resettings. An error of adjustment of one-tenth of a fringe will result, with 6-in. mirrors and a 2-in. aperture interferometer, in an error of 0.02 sec of arc.

The aperture limits the useful range of this device, but included angles as small as 2 deg can be utilized. The aperture at such small values can be increased by separating the mirrors—placing them at the desired angle but not meeting at the vertex.

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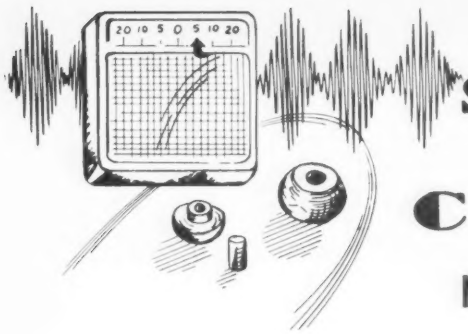
[1] Suggested arrangement of mirrors to form multiple reference angles, *by J. B. Saunders, J. Opt. Soc. Am.* **51,** *859 (Aug. 1961).*

[2] An introduction to interferometry, *Thomas O'Donnell, American Machinist, Spec. Rept. 490, 143 (June 1960).*

[3] Construction of a Kösters double-image prism, *J. B. Saunders, J. Research NBS* **58,** *21 (Jan. 1957).*



STANDARDS AND CALIBRATION

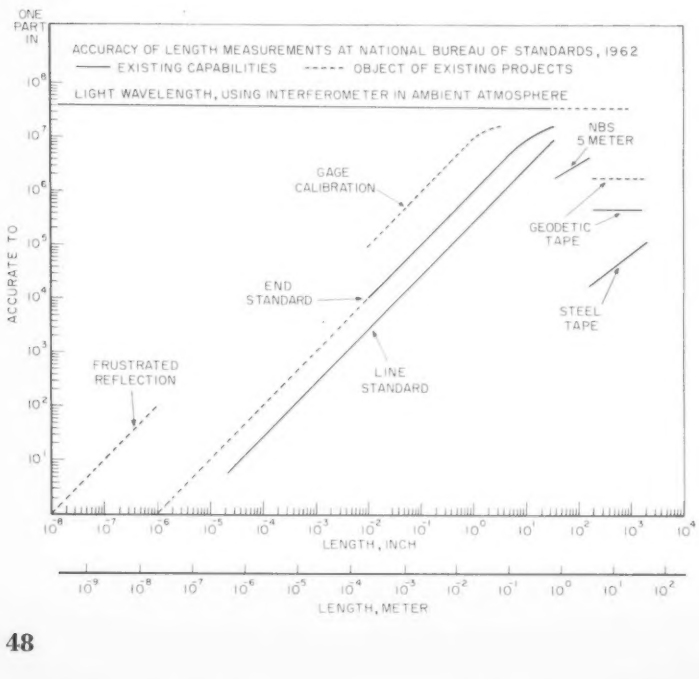
NBS Length Measurement Capability

THE ACCURATE determination of length is a requirement in many scientific experiments and in almost all phases of manufacture. To promote accuracy and uniformity in length measurements, the Bureau provides calibration services for both end standards and line standards.[1] The accuracies available at the Bureau in the calibration of certain devices used in length measurement are presented in the accompanying chart.[2]

In the chart solid lines depict present capabilities; dashed lines show the projected goals of current research programs. Accuracies in the chart are expressed at the 99-percent confidence level (3-sigma limits) in ratio to the length measured, plotted against length in inches.

At the top of the chart is shown the accuracy, in air, of the international standard of length—the wavelength of the orange-red line of krypton 86. End standards such as gage blocks [3] are often calibrated in terms of the wavelength scale. (When less accuracy is required, the Bureau calibrates gage blocks with an electromechanical comparator rather than with light waves.)

Demands for greater accuracy in the calibration of gage blocks are being met by research on a variety of fronts. As gage blocks themselves exhibit dimensional instabilities, a continuing program to develop more stable blocks is in progress.[4] Blocks having a dimensional change of no more than 1 part in 10 million per year have been developed, and an interferometer capable of determining length to this accuracy is nearing completion. At such accuracies even variations in the thickness of the wringing film between blocks, or between block and optical surface, will constitute an appreciable error, and a technique known as frustrated total reflection [5] is being studied in connection with the measurement of film thickness (curve at lower left).



This chart, one of a series on measurement prepared by the Bureau, depicts the current NBS capabilities in length measurements. Solid lines represent current capabilities; dashed lines show the goals of current research. Accuracies are with respect to the 99 percent confidence level (3-sigma limits) in ratio to the length measured, plotted against length.

Other advances in interferometry currently under development include an automatic fringe-counting device, a refractometer to determine the effect of the atmosphere on the wavelength scale, and the use of a helium-neon laser to provide light of greater coherence than is available from krypton 86.

The Bureau calibrates several types of line standards.[6] These include X- and H-shaped bars (noted as line standards on the chart) and steel and Invar (geodetic) tapes. Bar-type standards are calibrated by comparison with NBS standards, through the use of a longitudinal comparator with which observers can read to an uncertainty of 4 μin.

The NBS 5-m bar has been used to accurately locate the micrometer microscopes of a 50-m geodetic comparator. This comparator is used in the calibration of geodetic tapes, which are made of Invar to minimize thermal effects. The geodetic comparator has also been used to calibrate a master steel tape, which in turn was used to calibrate a steel tape bench. This 200-ft-long bench, consisting of interlocking stainless steel sections, is used in the calibration of steel tapes. Such tapes are calibrated with a lower accuracy than geodetic tapes because of the greater expansion coefficient of steel. The accuracy of some line-standard calibrations would be increased if the comparisons were made with the wavelength scale, and work is in progress to permit such calibrations.

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[1] *See* Test fee schedules of the National Bureau of Standards, *available from the Office of Technical Information, National Bureau of Standards, Washington 25, D.C.*

[2] *For further information, see* Length and mass calibration at NBS, *presented by T. R. Young at the August 1962 meeting of the National Conference of Standards Laboratories, the proceedings of which are to be published by NBS.*

[3] Calibration of gage blocks, *NBS Tech. News Bull.* **45**, *26 (Feb. 1961)*.

[4] Extremely stable gage blocks for precision measurements, *NBS Tech. News Bull.* **44**, *82 (May 1960)*.

[5] Frustrated total reflection—its application to proximity problems in metrology, *NBS Tech. News Bull.* **45**, *110 (July 1961)*.

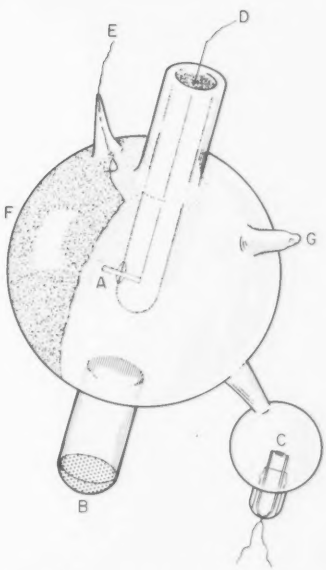
[6] Calibration of line standards of length and measuring tapes at the National Bureau of Standards, *Lewis V. Judson, NBS Mono. 15, available from Superintendant of Documents, U.S. Government Printing Office, Washington 25, D.C., 15 cents.*

CRYSTAL STUDIES by Electron Field Emission

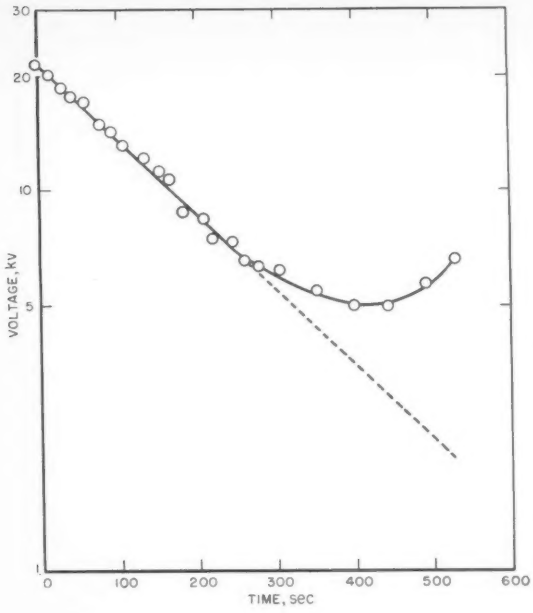
ELECTRON FIELD emission was recently used at the Bureau to study the growth of potassium and mercury single-crystal "whiskers" from the vapor phase. The work was conducted by R. L. Parker and S. C. Hardy of the metal physics laboratory as a part of a program to develop fundamental information on the crystallization process in metals.[1] The potassium experiments demonstrate the feasibility of using an alkali metal as a field emitter, and most of the data from the mercury experiments agree with those obtained by other investigators.[2]

When a metal surface is subjected to an electrostatic field of from 0.3 to 0.6 v/A, the potential energy barrier at the surface is lowered sufficiently to permit electrons to leak through. To obtain such high fields, an extremely sharp emitter, which is also strong enough to withstand electrostatic stresses up to 10^9 dynes/cm^2, must be used. Hence whiskers grown from the vapor phase frequently have the two basic requirements of electron field emitters; they are often only 100 to 1000 A in diameter, and they have very high strength.

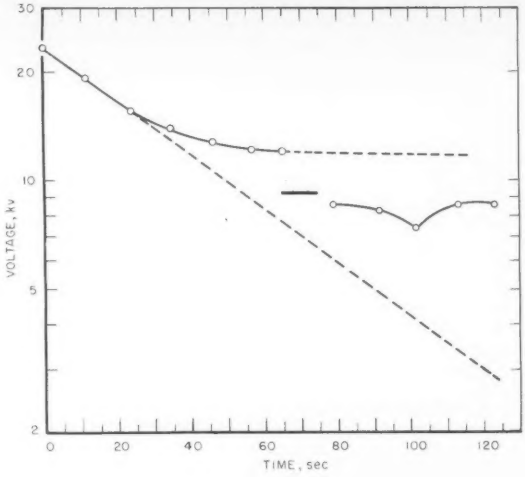
In field emission microscopy, the electrons which leave the tip of a metal whisker impinge on a fluorescent screen to form an enlarged image of the emitter tip. The electrostatic field required depends on the work function of the emitting surface; that is, the minimum energy necessary to remove an electron from the tip. This work function is determined by the atomic



Field emission tube used to grow metal whiskers which serve as the emitter. *A*, tungsten substrate for whisker growth; *B*, vapor source; *C*, getter filament; *D*, high-voltage lead; *E*, electric lead from fluorescent screen; *F*, fluorescent screen; *G*, sealoff tip of tube.



A typical "appearance" voltage versus time curve obtained in recent studies of the growth of potassium whiskers from the vapor phase. The whiskers were grown in an electron field emission tube under a pressure of 4.3×10^{-7} mm and at a temperature of 77 °K. The voltage required to obtain a pattern on the screen of the tube decreased in proportion to whisker growth, so that whisker length could be determined at specific time intervals. The terminal length, as indicated here, is achieved at about 420 sec.



A *V-t* curve obtained in field emission studies of a potassium whisker. At $t=65$ sec, the whisker was exposed for 10 sec to a light source while the electrostatic field was maintained at the value indicated by the horizontal bar. The light apparently caused a sudden drop in the curve. The dotted lines show theoretically derived curves.

arrangement in the emitting surface, with the most close-packed planes having the highest work function and emitting the least. Thus the screen patterns obtained show dark areas for high-work-function planes and light areas for low-work-function planes. From these patterns the planes corresponding to the symmetry of the pattern are identified and the orientation of the crystal is determined.

The spherical field emission tube used for the experiments (see illustration), approximately 15 cm in diameter and made of Pyrex, was partially coated on the inside with an optically transparent conducting layer, and phosphor was then deposited to form the screen. An external electric lead to the screen was sealed off at the side of the tube. A "cold finger," sealed into the neck of the tube and extending halfway inside, contained a conducting substrate made of tungsten rod. This rod extended through the lower wall of the finger in a horizontal position, so that the end protruding into the tube faced the screen. This end of the rod provided a surface on which a whisker could grow from the vapor phase. The other end of the rod, inside the finger, served as a terminal for a second electric lead.

The tube was prepared for crystal growth by attaching it through a Pyrex distillation train to a bakable, zeolite-trapped, ultra-high-vacuum system. About a gram of the metal under study was distilled three times in a residual vacuum of 10^{-9} to 10^{-10} mm Hg, then distilled directly into an extension at the bottom of the tube, after which the tube was sealed off.

In the experiments the tube was submerged in a temperature-controlled liquid bath. The substrate was held at a lower temperature by liquid nitrogen, dry ice-acetone, or by circulating oil in the cold finger. Thus the vapor in the tube became supersaturated and, after an induction period, a whisker started to grow horizontally on the end of the tungsten rod facing the screen. The voltage required to obtain a pattern on the screen decreased in proportion to whisker growth, so that the length of the whisker could be determined at specific time intervals. (See graph, above left, which presents a typical voltage-time curve for a potassium whisker.)

Experimental results obtained at different temperatures and for a number of specimens showed that mercury and potassium whiskers at first grow exponentially with time and that growth usually stops when a certain terminal length is reached. This behavior is in agreement with the theory which visualizes growth as taking place by the surface diffusion of atoms absorbed on the whisker from the vapor. These atoms then move over the whisker sides to the tip where they are built into the step provided by an emergent axial screw dislocation. In the potassium experiments, rather low surface self-diffusion parameters were obtained; however, similar experiments with mercury whiskers gave values that agreed with theory.

Some interesting effects were observed in the potassium experiments. For reasons which are not yet

clear, the patterns generally did not show symmetrically arranged dark and light areas. Instead, bright circular patches appeared, showing continual motion of the surface. This motion could be stopped by reducing vapor pressure. Occasionally clear regions of low emission momentarily appeared, and on these occasions both threefold and fourfold symmetry were observed.

When one voltage-time (V-t) curve (see graph, p. 50, right) was obtained for a potassium whisker, the whisker was exposed for a brief period to a light source while the field was kept on at a slightly lower value. A sudden drop occurred in the V-t curve during exposure both to infrared filtered light and to white light. The same effect could not be obtained with mercury whiskers. Other effects with potassium whiskers involving light and field were noted, but their interpretation is not certain. They are possibly related to sputtering in which ion bombardment pits the tip surface, causing local depressions and elevations.

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[1] *For further technical details, see* Vapor phase growth kinetics of potassium whiskers by field emission, *by R. L. Parker and S. C. Hardy, J. Chem. Phys.* **37,** *1606 (1962).*

[2] Field emission from mercury whiskers, *by R. Gomer, J. Chem. Phys.* **28,** *457 (1958);* Field emission from whiskers, *by A. J. Melmed and R. Gomer, J. Chem. Phys.* **34,** *1802 (1961).*

Research Highlights—1962

Research Highlights reviews the Bureau's activities in developing, maintaining, and extending the Nation's standards of physical measurement, and in investigating the physical constants and the basic properties of materials. It also gives highlights in the areas of the Bureau's special missions and responsibilities, including radio propagation, cryogenics, building research, and data processing. *Research Highlights* is directed toward research and industrial management, as well as to engineers and scientists.

Typical reports in *Research Highlights* are on—

—establishment at the Bureau of a gear metrology laboratory—believed to be the first of its kind in the country—to provide measurement standards in this important area;

—development of methods for measuring the diameters of master spheres up to 3 in. in diameter with an accuracy of two-millionths of an inch;

—development of an ultrasonic thermometer for use as a primary standard instrument in the 1.5 to 20 °K range;

—the second suborbital flight of the instrument package for the proposed "Topside Sounder" satellite, confirming its potential value as an important new source of information about the ionosphere;

—new value for the atomic weight of chlorine;

—direct visual observations of phase transitions in materials under pressures of more than a million pounds per square inch; and

—establishment of the Joint Institute for Laboratory Astrophysics (JILA) by NBS and the University of Colorado.

Additional features include: a report on the wide NBS cooperation with Federal, State, and local government agencies and with national professional societies and standardization groups, including the National Conference of Standards Laboratories. Bureau-industry cooperation includes the Research Associate Plan, conducted in collaboration with industrial and professional groups. On an international basis, the Bureau represents the interests of the Government and American sciences in matters dealing with the establishment and maintenance of standards, and the establishment of values for physical constants. It works through a large number of international groups, and frequently plays a major role in organizing international committees.

A complete list of the Bureau's publications for the fiscal year is also included.

Research Highlights of the National Bureau of Standards, Annual Report for fiscal 1962, National Bureau of Standards Miscellaneous Publication 246, issued December 1962, 217 pages, 70 cents. (Order from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.)

NOTE: Foreign remittances must be in U.S. exchange and should include an additional one-fourth of the publication price to cover mailing costs.

NBS Authors Contribute to Popular Science Texts

G. C. Paffenbarger and W. J. Youden have contributed to two science books aimed at the popular audience—high school students in particular. The books have been published in the "Vistas of Science" series published by the National Science Teachers Association.

The Vistas of Science series seeks to satisfy the "insatiable demand for current, accurate scientific information" created by the expanding frontiers of science, technology, and engineering. The books are aimed at the high school level, and not only provide basic information in the field but also give the student guidelines for experiments and investigations which he can carry out himself.

Dr. Paffenbarger, with Dr. Sholom Pearlman, secretary of the Council on Dental Research of the American Dental Association (ADA), has edited a new book—*Frontiers of Dental Science*. Dr. Paffenbarger is senior research associate of the ADA in the NBS dental laboratory.

Frontiers in Dental Science is a collection of writings by a number of authors on various aspects of dental science. The field is approached from the point of view of the various sciences—physics, biophysics, chemistry, etc., and then specialized technical topics, such as pharmacology and materials research, are added to this base. One article, on the use of tooth fluorescence as a tool for study of tooth material, was written by Dr. Alphonse F. Forziati and Mrs. Marion P. Kumpula, both of the NBS dental research laboratory.

Experimentation and Measurement, by W. J. Youden of the applied mathematics laboratory, has passed the 100,000 sales mark in its first year. Dr. Youden's book is a basic text on scientific measurement written from the mathematician's point of view.

Dr. Youden explains "laws of measurement" which are just as fascinating as the familiar laws of science. These laws help to recognize, understand, and remove sources of error in experimental measurements. By performing the outlined experiments and making the measurements required by them, the young reader gains an immediate appreciation of the role and problems of the measurement scientist.

Frontiers of Dental Science and Experimentation and Measurement are available at 50 cents each from Scholastic Book Services, 33 West 42d Street, New York 36, N.Y.

NBS Standard Frequency Broadcasts Unchanged for 1963

DURING 1963 the standard frequency broadcasts of the Bureau's stations WWV, WWVH, WWVL, and WWVB will continue to be offset from Ephemeris Time by 13 parts in 1 billion. This offset—which follows the current recommendation of the International Bureau of Time, Paris, France—is so slight that it cannot be detected by ordinary radio receivers. However, it could be significant to laboratories and industries making highly precise time or frequency measurements.

The standard frequency and time signals broadcast by NBS are regulated by cesium atomic standards. The cesium atoms "tick" 9,192,631,770 times during an ephemeris second, which is the international basis for scientific time. A time scale, UT2, on which we base the time of day, is determined by the period of the earth's rotation on its axis, which we subdivide into hours, minutes, and seconds. As the period of the earth's rotation is not constant—in fact, varies from day to day—the length of the second as given by the atomic standards does not exactly coincide with the second determined from the earth's rotation. Therefore, the broadcast signals are offset from the scientific scale as much as is necessary to keep them in close agreement with UT2.

During 1962 the International Bureau of Time consulted observatories throughout the world and compared astronomical and atomic measurements of time. From these data the average variation from Ephemeris Time expected in the speed of the earth's rotation during 1963 was determined. Their findings indicate a difference of about 13 parts in a billion—the same value as was used in 1962. Thus, the correct frequency on the ephemeris scale can be determined by adding 13 parts in a billion to the frequency signal as received.

Publications of the National Bureau of Standards

Periodicals

Technical News Bulletin, Vol. **47**, No. 2, February 1963. 15 cents. Annual subscription: $1.50, 75 cents additional for foreign mailing. Available on a 1-, 2-, or 3-year subscription basis.

CRPL Ionospheric Predictions for May 1963. Three months in advance. Number 2, issued February 1963. 15 cents. Annual subscription: $1.50, 50 cents additional for foreign mailing. Available on a 1-, 2-, or 3-year subscription basis.

Journal of Research of the National Bureau of Standards

Section A. Physics and Chemistry. Issued six times a year. Annual subscription: Domestic, $4; foreign, $4.75.

Section B. Mathematics and Mathematical Physics. Issued quarterly. Annual subscription: Domestic, $2.25; foreign, $2.75.

Section C. Engineering and Instrumentation. Issued quarterly. Annual subscription: Domestic, $2.25; foreign, $2.75.

Section D. Radio Propagation. Issued six times a year. Annual subscription: Domestic, $4; foreign, $4.75.

Current Issues of the Journal of Research

Section B. Mathematics and Mathematical Physics, vol. **67B,** No. 1, Jan.–Mar. 1963

Evaluation of a generalized elliptic-type integral. L. F. Epstein and J. H. Hubbell.

An algorithm for obtaining an orthogonal set of individual degrees of freedom for error. J. M. Cameron.

Recognition of completely mixed games. A. J. Goldman.

A new type of computable inductor. C. H. Page.

Numerical computation of the temporal development of currents in a gas discharge tube. W. Börsch-Supan and H. Oser.

Tables of genera of groups of linear fractional transformations. H. Fell, M. Newman, and E. Ordman.

Section C. Engineering and Instrumentation, Vol. 67C, No. 1, Jan.–Mar. 1963.

Method for calibrating a standard volt box. B. L. Dunfee.

Stability of residual thiosulfate in processed microfilm. C. I. Pope.

Equipment for single crystal growth from aqueous solution. J. L. Torgesen, A. T. Horton, and C. P. Saylor.

An automatic multichannel correlator. R. F. Brown, Jr.

Elastic constant—porosity relations for polycrystalline thoria. S. Spinner, F. P. Knudsen, and L. Stone.

An oxygen partial pressure warning instrument. L. Greenspan.

New fast-opening, large-aperture shutter for high-speed photography. E. C. Cassidy and D. H. Tsai.

Equations for the radiofrequency magnetic permeameter. C. A. Hoer and A. L. Rasmussen.

Nonperiodicals

NBS viscometer calibrating liquids and capillary tube viscometers, R. C. Hardy, NBS Mono. 55 (Dec. 26, 1962), 20 cents.

Equipment characteristics and their relation to system performance for tropospheric communication circuits, A. F. Barghausen, F. O. Guiraud, R. E. McGavin, S. Murahata, and R. W. Wilber, NBS Tech. Note 103 (Jan. 15, 1963), $1.00.

The thermodynamic properties of nitrogen from 114 to 540° R between 1.0 and 3000 psia, Supplement A. (British units), T. R. Strobridge, NBS Tech. Note 129A (Feb. 1963), 50 cents.

The construction of calorimeters for the measurement of absorbed dose, B. Petree and G. Ward, NBS Tech. Note 163 (Nov. 1962), 25 cents.

Fading correlation bandwidth and short-term frequency stability measurements on a high-frequency transauroral path, J. L. Auterman, NBS Tech. Note 165 (Oct. 1962), 40 cents.

Publications in Other Journals

This column lists all publications by the NBS staff, as soon after issuance as practical. For completeness, earlier references not previously reported may be included from time to time.

Growth rates of potassium crystal from the vapor phase, R. L. Parker, J. Chem. Phys. **37**, No. 8, 1600–1605 (Oct. 1962).

Ranking laboratories by round-robin tests, W. J. Youden, Mater. Res. Std. **3**, No. 1, 9–13 (Jan. 1963).

The NBS photoelectric pyrometer of 1961, R. D. Lee, Book, Temperature, Its Measurement and Control in Science and Industry 3, Pt. 1, 507–515 (Reinhold Publ. Corp., New York, N.Y., 1962).

The error rate in a multiple-frequency-shift system and the output signal/noise ratio in a frequency modulation and a pulse-code-modulation/frequency-shift system, H. Akima, Intern. Conf. Satellite Communication, pp. 305–310 (Nov. 22–28, 1962).

Heat transfer in intensively outgassed powders, R. C. Little, F. G. Carpenter, and V. R. Deitz, J. Chem. Phys. **37**, No. 8, 1896–1898 (Oct. 15, 1962).

Rates of thermal degradation of organic polymers, S. L. Madorsky, SPE J. **18**, No. 12, 1482–1490 (Dec. 1962).

Vacuum ultraviolet photochemistry. V. Photolysis of isobutane, H. Okabe and D. A. Becker, J. Am. Chem. Soc. **84**, No. 21, 4004–4007 (1962).

Traces of products of angular momentum matrices. II. Spherical basis, E. Ambler, J. C. Eisenstein, and J. F. Schooley, J. Math. Phys. **3**, No. 4, 760–771 (July–Aug. 1962).

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The present state of atomic spectra, C. M. Moore-Sitterly, Japan Anal. **11**, No. 11, 1199–1202 (1962).

Correlation factors for impurity diffusion-fcc lattice, J. R. Manning, Phys. Rev. **128**, No. 5, 2169–2174 (Dec. 1962).

A differential thermocouple voltmeter, J. E. Griffin and F. L. Hermach, AIEE Trans., Pt. I. Communications and Electronics No. 63, Article No. 62–819, 338–344 (Nov. 1962).

Color tests for antioxidants, E. J. Parks, L. T. Milliken, and F. J. Linnig, Rubber Age **92**, No. 2, 257–261 (Nov. 1962).

Cavitation problems in cryogenics, R. B. Jacobs and K. B. Martin, J. Basic Eng. **82**, 756–757 (Sept. 1960).

Experimental proof of the absence of equilibrium in a helium arc, A. T. Hattenburg and H. J. Kostkowski, Book, Temperature, Its Measurement and Control in Science and Industry 3, Pt. 1, 587–592 (Reinhold Publ. Corp., New York, N.Y., 1962).

Technical training in the weights and measures program, M. W. Jensen, Scale J. **49**, No. 4, 4–5 (Jan. 1963); Southern Weights and Measures Program **14**, No. 12, 2–5 (Dec. 1962).

Corrosion rates of ferrous alloys (Fe, Cr, and Fe-Cr-Si) measured by polarization techniques, W. J. Schwerdtfeger, Corrosion **19**, No. 1, 17t–25t (Jan. 1963).

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On the analysis of polarization rotation recordings of satellite radio signals, R. S. Lawrence and C. G. Little, Intern. Sci. Radio Union, IGY Comm. Some Ionospheric Results Obtained During the IGY; Proc. Symp. Organized by URSI/AGI Comm. Brussels, Belgium, pp. 391–399 (Elsevier Publ. Co., Amsterdam, The Netherlands, 1960).

Widely separated clocks with microsecond synchronization and independent distribution system, T. L. Davis and R. H. Doherty, IRE WESCON, Conv. Pt. 5, pp. 3–17 (1960).

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Measurement of electron density and temperature in dense plasmas by application of line broadening theory, J. B. Schumaker, Jr., and W. L. Wiese, Book, Temperature, Its Measurement and Control in Science and Industry 3, Pt. 1, 575–579 (Reinhold Publ. Corp., New York, N.Y., 1962).

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Isotope effect in the recrystallization of D-mannose-l-*t*, phenylhydrazone, F. Weygand, H. Simon, K. D. Keil, H. S. Isbell, and L. T. Sniegoski, Anal. Chem. **34,** 1753–1755 (Dec. 1962).

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Polymorphism in fibrous polypeptides: $\alpha \rightleftarrows \beta$ transformation in naturally occurring keratin, A. F. Diorio, L. Mandelkern, and E. R. Lippincott, J. Phys. Chem. **66,** No. 11, 2096–2100 (Nov. 1962).

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